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- Concentrator,
- Biplexor.

The availability probabilities are determined by subtracting the failure probabilities from unity. These values are given below for the five components of the model:

Availability Component	Failure Probability	Availability[4] Probability
A_{LIN}	0.001769[1]	0.999997
A_{SW}	0.01414[2]	0.9998
A_{CON}	0.01414[2]	0.9998
A_{MDM}	0.000344[1]	0.9999999
A_{BPX}	0.0005[3]	0.9999998

NOTES:

1. Values from NAC final report FR.163.01.
2. Values from NADIN Specification (FAA-E-2661).
3. Value estimated by NAC.
4. Assumes redundant component.

The communications availability for the NFDC-CNS/AIS and CNS-AWP node pairs may be modeled as series systems since the line and equipment redundancies are included in the availability probabilities. The availability for the CNS-AWP node pairs is the same for all alternatives; however, the NFDC - CNS/AIS availability is determined for the different message types (i.e., NOTAMs, interactive AIS and batch AIS) for each alternative.

The general model for the series systems is given by the equation

$$A_{COM} = A_{LIN}^{TNL} \; A_{SW}^{NSW} \; A_{CON}^{NCN} \; A_{MDM}^{2\ NSL + 4\ NDL} \; A_{BPX}^{2\ NDL}$$

where A_{COM} = communications availability for a node pair,

A_{LIN} = availability of a line,

A_{SW} = availability of a NADIN switch,

A_{CON} = availability of a NADIN concentrator,

A_{MDM} = availability of a modem,

A_{BPX} = availability of a biplexor,

TNL = total number of lines in the link connecting the node pair (TNL = NSL + NDL + NCB),

NSW = number of switches in the link connecting the node pair,

NSL = number of single lines in the link connecting the node pair,

NDL = number of dual lines in the link connecting the node pair,

NCB = number of cable connections.

Because the WMSC may communicate directly with either NADIN switch the availability for the CNS-WMSC node pair was modeled separately. The availability of the CNS-WMSC link is determined by forming the product of the availabilities of the CNS-ZTL segment and the ZTL-WMSC segments. Because of the two possible paths between ZTL and WMSC, the availability of the ZTL-WMSC segment is a function of the failures of the paths between ZTL and WMSC, between ZTL and ZLC, and between ZLC and WMSC.

The availability of the ZTL-WMSC system is given by:

$$P(A) = 1 - P(F),$$

where

$P(A) =$ probability of availability and

$P(F) =$ probability of complete system failure.

The complete system fails under the following conditions:

- the link between ZTL and WMSC fails, and
- the link between ZTL and ZLC fails, or the link between ZLC and WMSC fails, or both.

Symbolically, the probability of this system failure, P(F), is given by:

$$P(F) = P(F_2) \cap (P(F_3) \cup P(F_4)),$$

where

$P(F_2) =$ probability of failure for the ZTL-WMSC link,

$P(F_3) =$ probability of failure for the ZTL-ZLC link, and

$P(F_4) =$ probability of failure for the ZLC-WMSC link.

The $\cap$ and $\cup$ notation indicates the intersection and union, respectively, of the events F_i. From elementary probability theory, the above expression for P(F) translates into

$$P(F) = P(F_2)\,(P(F_3) + P(F_4) - P(F_3) \bullet P(F_4)).$$

The only assumption is that the failures of the three links are independent of each other.

Combining the above expression with the availability of the CNS-ZTL link, the total availability, A_{COM}, of the CNS-WMSC link is given by:

$$A_{COM} = (1-P(F_1))\,(1-P(F_2)\,(P(F_3) + P(F_4) - P(F_3)P(F_4))),$$

where $P(F_1)$ = probability of failure for the CNS-ZTL link, and $P(F_2)$, $P(F_3)$ and $P(F_4)$ have the same definitions as given previously.

The probabilities of availability are given for the four node pairs below:

NFDC-CNS/AIS

Alternative 1: NOTAMS - A_{COM} = 0.999591

Interactive AIS - A_{COM} = 0.999997

Batch AIS - A_{COM} = 0.999997

Alternative 2: NOTAMs & Interactive AIS - A_{COM} = 0.999591

Batch AIS - A_{COM} = 0.999997

Alternative 3: NOTAMs - A_{COM} = 0.999997

Interactive AIS - A_{COM} = 0.999997

Batch AIS - A_{COM} = 0.999997

Alternative 4: All Traffic - A_{COM} = 0.999589

CNS - AWP_1

A_{COM} = 0.999794

CNS - AWP_2

A_{COM} = 0.999590

CNS - WMSC

A_{COM} = 0.998020

APPENDIX F

PROTOCOL OVERHEAD FOR NFDC/IS CIRCUITS

F.1 Purpose

The overhead for the various protocol types that will be used in the circuits of NFDC/IS is modeled in order to determine the total bit rate for those circuits.

F.2 Protocol Categories

There are four types of link level protocols that will be used by the nodes of the NADIN support alternatives: ADCCP, Category B, Teletype and Binary Synchronous.

F.3 Protocol Overhead Models

The circuits of the NADIN support alternatives may be grouped into three categories accoridng to their link level protocol. The groups are referred to by their link level protocol (i.e., ADCCP, Category B, Teletype and Binary Synchronous), and their total overhead is described below.

F.3.1 ADCCP

There are two groups of circuits that use the ADCCP link level protocol:

- AWP - circuits between the NADIN switches and the AWPs.
- NADIN Backbone - circuits between NADIN switches and between a NADIN switch and a NADIN concentrator.

The link level protocol overhead model for the two groups listed above is the same for both categories because of their comparable message lengths.

F.3.1.1 Link Level Overhead

The advanced data communications control protocol (ADCCP) is a bit oriented data link control procedure that will be used between the NADIN switching centers, between the switching centers and the concentrators and may also be used to interface between NADIN and other systems outside the network (Appendix A, NADIN Specification, FAA-E-2661). Appendix A of the NADIN specification refers to Federal Standard FED-STD-1003, which in turn refers to the ANSI standard X3.66-1979. Specifically, the ADCCP procedure provides for:

- data link in a two-way simultaneous or two-way alternate mode,
- operation over synchronous transmission facilities,
- modulo-8 numbering of blocks and acknowledgements,
- retransmission of unaceptable blocks,
- cyclic redundancy check (CRC) algorithm for error detection,
- zero insertion in the information field bit stream,
- maximum of 3,700 ASCII characters for the length of the entire message.

The link level protocol overhead for the AWP and NADIN backbone categories is categorized by function below:

Header and Trailer: (Figure F.1) The header and trailer consist of 48 bits (start flag, address, control character, frame check sequence and stop flag). It is assumed that the information field is equal, on the average, to 1000 bits (125 characters). This length is comparable to the length of NADIN messages and results in an average overhead of 4.8%.

Zero Insertion: A flag consists of the sequence 01111110. This sequence may occur in the frame bit stream between flags. To prevent it from being erroneously interpreted as a flag, the transmitter inserts a zero each time it detects five successive ones. It can be shown that, assuming a random bit pattern, the average number of bits transmitted until a zero is inserted is $2 \times (2^5 - 1) = 62$ bits and this results in an average overhead of 1/62 = 1.6%. If the assumption of random bit patterns is relaxed, the zero insertion overhead can be lower or higher but it cannot exceed 1/5 = 20% in any case.

Retransmitted Frames: Frames which contain errors and subsequent frames are retransmitted. In Appendix G, it is shown that the average overhead is 2.5% for retransmission of frames. This assumes a bit error probability of 5×10^{-6}, and an average of 4 retransmitted frames for each detected incorrect frame.

Supervisory and Management Frames: The ADCCP uses several types of supervisory and management frames which are usually short. No attempt at enumeration is made here but the overhead is estimated to be a maximum of 3%.

These link level overheads are summarized in Table F.1.

F.3.1.2 AWP Message Overhead

The main contribution to overhead at the message level is due to the supervisory information included in the heading. Since it is not clear yet what information is going to be included, expecially in the optional data field, it was conjectured that the total of heading and ending characters is 36 and that the optional data field contains 27 characters (i.e., half the maximum of 54 charactes), giving a total of 63 extra characters (see Table F.2). The message overhead for the AWP to NADIN switch and NADIN switch to AWP traffic has been documented in NAC WM.303A.04, "FSAS/NADIN Interface". The AWP to NADIN switch message overhead was determined to be 25.45 percent of the message volume (i.e., the information field of a message frame). The NADIN switch to AWP message overhead was determined to be 35.72 percent.

In addition to the overhead due to header, an extra 3% of overhead due to system management messages is assumed.

F.3.1.3 NADIN Backbone Message Overhead

Information and network management messages which transit the backbone circuits of NADIN (i.e., switch to switch and switch to concentrator/concentrator to switch) require a communications control field (CCF) (Section 3.3.4.2, NADIN Specification, FAA-E-2661). The CCF comprises all information required to exercise communication control; i.e., all the control functions required for correct message handling after the message or message part has cleared the data link control field (DLCF) function. Figure F.2 shows the position of the CCF and the communications data field (CDF) within the format of a message frame. The DLCF represents the ADCCP linking procedure. The CCF and the CDF together comprise the link data field which contains a maximum of 1,950 bits.

The overhead for the CCF function is modeled for three categories of backbone traffic: switch to switch, concentrator to switch and switch to concentrator. For the switch to switch and concentrator to switch messages the CCF is 40 bits , and for the switch to concentrator messages the CCF is 56 bits (the two additional octets are for additional terminal addresses). Assuming an average NADIN message length of 1,000 bits, the overheads for the three categories are:

Switch to Switch:	40/1,000	=	4%
Concentrator to Switch:	40/1,000	=	4%
Switch to Concentrator:	56/1,000	=	5.6%

An additional 3% overhead is assumed for network management messages.

F.3.2 Category B

The Category B protocol will be used in the interface for the WMSC-NADIN, NFDC-NADIN, CNS-NADIN and NFDC-CNS links.

F.3.2.1 Link Level Overhead

The Category B protocol is a character oriented, full duplex data link control procedure that may be used between external systems and NADIN (Appendicies C and G, NADIN Specification, FAA-E-2661). The properties of this protocol are summarized below:

- Two-way simultaneous switched (or nonswitched),
- Point-to-Point,
- Message associated blocking,
- Modulo 3 numbering of blocks and acknowledgements for WMSC-NADIN,
- Modulo 8 numbering of blocks and acknowledgements for NFDC-NADIN, CNS-NADIN and NFDC-CNS,
- Synchronous operation,
- Maximum block length is 240 ASCII characters,
- Block check character employs longitudinal redundancy check for error control,
- Retransmission of unacceptable blocks.

The overhead associated with the Category B protocol is grouped according to the funtions:

- Establishment and termination,
- Message transfer,
- Retransmission of blocks,

Establishment and Termination: the establishment procedure or hand shaking between two nodes using Category B is accomplished by a set of supervisory sequences that are exchanged between the calling station and the called station. This sequence consists of eight characters. The termination procedure normally consists of a supervisory sequence of four characters (i.e., in the case a link has been established). In addition to the overhead for establishment and termination procedures, three SYN characters per supervisory sequence

are sent. Assuming two supervisory sequences each for the calling station and the called station for each sending/receiving session, there are 12 characters associated with this overhead. The total overhead associated with this category is 24 characters. Assuming an average information field length of 125 characters the resulting overhead is 19.2%.

Message Transfer: The overhead for the message transfer procedure consists of five characters trasmitted by the calling station and four by the receiving station. In addition there are three SYN characters for each supervisory sequence or a total of six in this case. The total overhead due to message transfer overhead is 15 characters. Using the same average message length as before (i.e., 125 characters), the overhead is 12%.

Retransmission of Blocks: The retransmission of message blocks is due to one of two causes: a block check error detected by the receiving station or a failure by the receiving station to respond to a received block within a specified time range (called a timeout).

When the receiving station detects one or more errors in a block, it sends the transmitting station a supervisory message. The transmitting station must then retransmit all of the blocks that were transmitted after the one in error since they are ignored by the receiving station (this number is a maximum of two for the WMSC-NADIN link and seven for the NFDC-NADIN, CNS-NADIN and NFDC-CNS links). The retransmission overhead for error detection is defined by

$$EOH = \frac{3P}{1-P},$$ for the WMSC-NADIN link where two frames are retransmitted for each block error detected, and

$$EOH = \frac{5P}{1P},$$ for the NFDC-NADIN, CNS-NADIN and NFDC-CNS links where four frames are retransmitted for each block error detected.

EOH = expected overhead blocks and P = the probability that a block contains one or more errors (See Appendix G). Assuming a value for P of 0.005 the average overhead is 1.5% for the WMSC-NADIN link and 2.5% for the NFDC-NADIN, CNS-NADIN and NFDC-CNS links.

If a receiving station fails to respond to a block received within a specified time range, the transmitting station sends a reply-request supervisory sequence. If there is no response from the receiving station after three such sequences, then recovery procedures are initiated by the transmitting station. In Appendix H it is shown that the overhead due to this category is 0.5% for all links using the Category B protocol.

The total overhead for the retransmission of blocks is the sum of the two individual overheads given below: 2% for the WMSC-NADIN links and 3% for the NFDC-NADIN, CNS-NADIN and NFDC-CNS links.

The link level overhead is summarized in Table F.3.

F.3.2.2 WMSC to NADIN Switch Message Overhead

The WMSC to NADIN switch message overhead is illustrated in Figure F.3, and the number of overhead characters is given below.

FIELD	NUMBER OF CHARACTERS
Start of Header	1
Priority	1
Delineator Space	1
Address	8
Delineator	4
Optional Data Field	27
Delineator	2
Start of Text	1
Message Separator	3
End of Text	1
Total	49

Assuming an average message length of 125 characters the message overhead of the WMSC to NADIN switch messages is 39.2%. An additional 3% is assumed for WMSC to NADIN switch service messages.

F.3.2.3 NADIN Switch to WMSC Message Overhead

The NADIN switch to WMSC message overhead is illustrated in Figure F.4, and the number of overhead characters is given below:

FIELD	NUMBER OF CHARACTERS
Start of Header	1
Start of Text	1
Message Seperator	3
End of Text	1
Total	6

Assuming an average message length of 125 characters the message overhead for NADIN switch to WMSC messages is 4.8%. An additional 3% overhead is assumed for NADIN switch to WMSC status messages.

F.3.2.4 NFDC to CNS Message Overhead

The message format for NOTAM traffic going from the NFDC to the CNS via NADIN or a dedicated line has not been determined. NFDC personnel have indicated that the format will probably be short. It is assumed that the format will be similar to that of the WMSC to NADIN messages but with the absence of the optional data field. The number of overhead characters per 125 character message is assumed to be 10. Therefore, the message level overhead for the NFDC to CNS, NFDC to NADIN and CNS to NADIN messages is 8%.

F.3.2.5 CNS to NFDC Message Overhead

A similar assumption to the one made for the NFDC to CNS message format is made for the CNS to NFDC, NADIN to NFDC and NADIN to CNS circuits: i.e., since no message format has been determined, it is assumed that the message level overhead will be the same as the NADIN to WMSC category, or 4.8%.

F.3.3 Teletype

The NFDC plans to continue the use of a Teletype (TTY) protocol for the interactive AIS traffic between the NFDC terminals and the AIS host if there is a dedicated circuit between the NFDC and the AIS.

F.3.3.1 Link Level Overhead

The TTY link level protoccol to be employed for the interactive AIS terminals is a half duplex, asynchronous procedure. The main contribution to the link level overhead is the start/stop bits associated with each ASCII character. Messages will be collected in store-and-forward devices at the NFDC and the AIS and are transmitted one character at a time with three bits for the start/stop function. Thus, the overhead due to this function is 37.5%. Although the TTY protocol does not provide an error detection scheme, it is assumed that such a function will be implemented. The overhead associated with this function is assumed to be 3%.

F.3.3.2 Message Level Overhead

The message format for the interactive AIS messages will not need to be very long or elaborate since these messages will be transferred by a dedicated line between the NFDC and the AIS. A message level overhead of six characters, or 12% based on a 50 character message length, is assumed for this category.

F.3.4 Binary Synchronous

For the circuit between the NFDC and the AIS dedicated to batch traffic, the half duplex Binary Synchronous (BSC) protocol will be used.

F.3.4.1 Link Level Overhead

The overhead for the BSC protocol is assessed for three categories: establishment and termination, message transfer and retransmission of blocks.

Establishment and Termination: the hand shaking procedure between the called station and the calling station amounts to 14 characters. Based on an information packet of 250 characters, this overhead category amounts to 5.6%.

Message Transfer: the message transfer procedure consists of 10 characters which amounts to 4% overhead. Figure F.5 illustrates the components of the BSC frame format.

Retransmission of Frames: the BSC protocol uses a cyclic redundancy check (CRC) scheme for error detection. The overhad associated with retransmisison of frames due to error detection is assumed to be the same as the counterpart function for the ADCCP protocol (i.e., 2.5%) since both protocols use a CRC function.

The link level overhead for the BSC protocol is summarized in Table F.4.

F.3.4.2 Message Level Overhead

The number of overhead characters contained in the message format for the point-to-point delivery of batch AIS messages is assumed to be a maximum of six (i.e., 2.4% based on an information frame of 250 characters). This format should not contain very much overhead since there is no need for addressing or priority fields in the format.

F.3.4 Total Overhead

The total overhead is assessed for the NFDC/IS circuits in order to determine the total bit rate for those circuits. The types of link and message protocol overheads listed above are "transparent" to one another; mathematically, this means that the total overhead is determined multiplicatively rather than additively. The basic model for the total overhead is given by:

$$1 + TOH = \prod_{i=1}^{n} (1 + IOH_i)$$

where TOH = total overhead,

IOH_i = an individual overhead and

n = the number of individual overhead categories.

The Pi, π , notation indicates the product over all the values of the term in parentheses. The total overhead is assessed for the four link level protocol groups and the different message formats within each group.

ADCCP Total Overheads

(i)	AWP to NADIN Switch:	1.124 x 1.2545 x 1.03 = 1.452
(ii)	NADIN Switch to AWP:	1.124 x 1.3572 x 1.03 = 1.571
(iii)	NADIN Switch to NADIN Switch:	1.124 x 1.04 x 1.03 = 1.204
(iv)	NADIN Concentrator to NADIN Switch:	1.124 x 1.04 x 1.03 = 1.204
(v)	NADIN Switch to NADIN Concentrator:	1.124 x 1.056 x 1.03 = 1.223

Category B Overheads

(i)	WMSC to NADIN	1.362 x 1.392 x 1.03 = 1.953
(ii)	NADIN to WMSC	1.362 x 1.048 x 1.03 = 1.427
(iii)	NFDC to CNS	1.372 x 1.08 = 1.482
(iv)	NFDC to NADIN	1.372 x 1.08 = 1.482
(v)	CNS to NADIN	1.372 x 1.08 = 1.482
(vi)	CNS to NFDC	1.372 x 1.048 = 1.438
(vii)	NADIN to NFDC	1.372 x 1.048 = 1.438
(viii)	NADIN to CNS	1.372 x 1.048 = 1.438

Teletype Overhead

(i)	NFDC to AIS	1.375 x 1.120 = 1.540
(ii)	AIS to NFDC	1.375 x 1.120 = 1.540

Binary Synchronous Overhead

(i)	NFDC to AIS	1.126 x 1.024 = 1.153
(ii)	AIS to NFDC	1.126 x 1.024 = 1.153

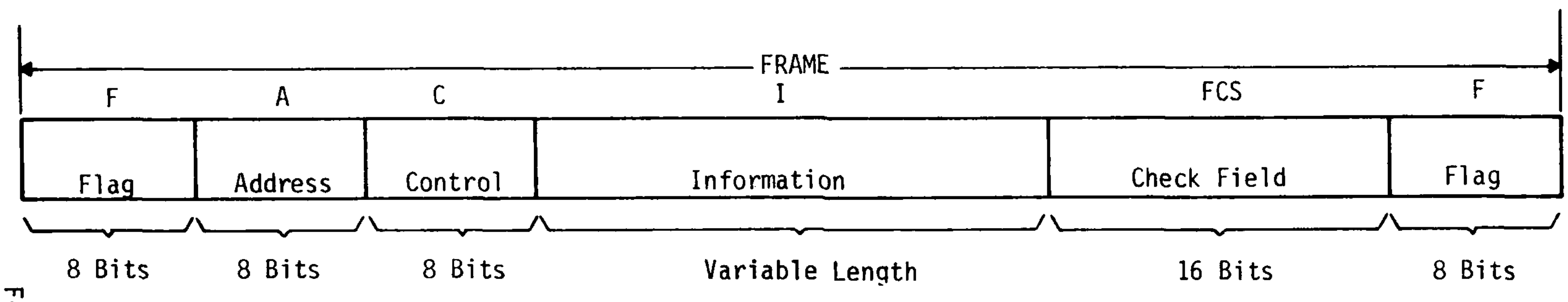

FIGURE F.1: ADCCP FRAME FORMAT

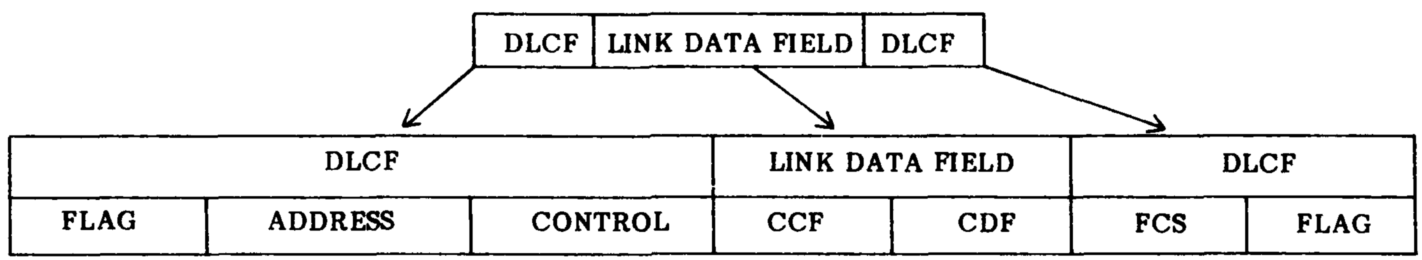

FIGURE F.2: DATA LINK CONTROL FIELD AND LINK DATA FIELD FOR NADIN BACKBONE MESSAGES

Start of Header	Priority	Delineator Space	Address	Delineator	Optional Data Field	Delineator	Start of Text	Text	Message Separator	*End of* Text

FIGURE F.3: WMSC TO NADIN SWITCH MESSAGE FORMAT

Start of Header	Start of Text	Text	Message Separator	End of Text

FIGURE F.4: NADIN SWITCH TO WMSC MESSAGE FORMAT

SYN	DLE	STX	FLC	DATA	DLE	ETX	CRC	PAD

FIGURE F.5: BSC FRAME FORMAT

Type of Overhead	Percentage Overhead
Heading and end of frame	4.8%
Zero insertion	1.6%
Retransmitted frames	2.5%
Supervisory frames	3.0%
TOTAL*	12.5%

* See section F.3.4 for algorithm for calculation of TOTAL

TABLE F.1: ADCCP OVERHEAD

Name of Leader	Length Min	Max	Assumed	Comment
Message Heading				
Start of heading	2	2	2	Same for all messages
Supervisory information	2	69	7	Transmission identification. Not mandatory when recovery is not required.
Priority	2	2	2	One of seven priorities
Addresses	4m	9m	9	One message can go to m locations
Date Time group	6	6	6	Day, hour and minute message was prepared.
Message originator	4	9	9	Address of originator
Length Subtotal	20		35	
Subfield A of Optional Data Field				
Message type	3	8		e.g. Graphics, Baudot
Privacy	2	2		Type of privacy
Acknowledgement	1	1		Defines type of system acknowledgement
Billing	1	1		Class of billing
Text code and format	2	2		For non ASCII texts
Text length	4	4		Mandatory for graphics
Subfield B of Optional Data Field				
Authentication key	6	8		For privacy
Possible duplicate message	3	3		Used in case accountability is needed during recovery
File number				ADP file number
Data Sequence Number	2	2		For messages exceeding 3700 characters.
Subfield C of Optional Data Field				
Additional information now undefined.				
Total length for A,B,C			27	
Message Text	0	3700		
Message ending	1	1	1	ASCII ETX
Total overhead	45	129	63	

TABLE F.2: STRUCTURE OF NADIN MESSAGE

Type of Overhead	Percentage Overhead
Establishment and Termination	19.2%
Message Transfer	12.0%
Retransmission of Blocks	2.0% or 3.0% **
*TOTAL	36.2% or 37.2% **

* See Section F.3.4 for algorithm for calculation of TOTAL.

** First number is the WMSC-NADIN link; second number is for NFDC-NADIN, CNS-NADIN and NFDC-CNS links.

TABLE F.3: CATEGORY B OVERHEAD

Type of Overhead	Percentage Overhead
Establishment and Termination	5.6%
Message Transfer	4.0%
Retransmission of Blocks	2.5%
*TOTAL	12.6%

* See Section F.3.4 for algorithm for calculation of TOTAL.

TABLE F.4: BSC OVERHEAD

APPENDIX G

ADCCP OVERHEAD DUE TO RETRANSMITTED FRAMES

G.1 PURPOSE

In this appendix the overhead due to retransmitted frames in the ADCCP protocol is modeled. This overhead is combined with other overhead categories (in Appendix F) to determine the total bit rates for circuits where the nodes use the ADCCP protocol.

G.2 MODEL

When the receiving station detects one or more errors in a frame it rejects this frame. Eventually, the transmitting station knows that the frame was rejected and retransmits it as well as all the subsequent frames. Since the number of unacknowledged frames ranges from 0 to 7, it is assumed that whenever an error occurs an average of 4 frames are retransmitted. Of course, it is possible that one or more of these frames will also be in error. The following sequence of events can happen when Station A transmits a frame to Station B, given that p is the probability that a frame is erroneous.

A Transmits	B Transmits	With probability
1 information frame		1
	1 supervisory frame	p^2
4 information frames		p
	1 supervisory frame	p
4 information frames		p^2
...	...	

As a result:

$$\text{Expected number of overhead frames} = p + 4p + p^2 + 4p^2 + \ldots$$

$$= 5p + 5p^2 + \ldots$$

$$= \frac{5p}{1-p}$$

It remains to calculate p, the probability that a frame is incorrect. With a bit error rate, BER, p is equal to one minus the probability that none of m bits of the sequence is in error.

$$p = 1 - (1\text{-BER})^m$$

assuming a bit error rate of 0.5×10^{-5} and assuming 1000 bits in a frame gives:

$$p = 0.004988,$$

and the average overhead is, from the above equation:

Overhead = 2.5%.

APPENDIX H

CATEGORY B OVERHEAD DUE TO NO RESPONSE

H.1 PURPOSE

The overhead due to no response for the Category B protocol is modeled in this appendix. This overhead is combined with other overhead categories (in Appendix F) to determine the total bit rates for circuits where the nodes use the Category B protocol.

H.2 MODEL

If a receiving station does not respond to a received block within a specified time, a reply-request (R-R) sequence is sent by the transmitting station. After three such sequences with no response, recovery procedures are initiated by the transmitting station. The recovery procedures consists of the following:

1. transmission of end-of-transmission character (EOT);

2. initiate the establishment procedure;

3. attempt (A) message retransmission three more times;

4. send message to supervisory position if retransmission not successful.

The following sequence describes the events that can happen when Station Y does not respond to a block received from Station X. Note that q is the probability that Station Y does not respond to a frame, and r is the probability that Station Y does not respond to a latter attempt to deliver the message block.

Event (Ei)		Probability P(Ei)	Number of Blocks N(Ei)
1.	Y does not respond initially	q	
2.	Y responds to $(R\text{-}R)_1$	q x (1-r)	1
3.	Y responds to $(R\text{-}R)_2$	q x r x (1-r)	2
4.	Y responds to $(R\text{-}R)_3$	q x r^2 x (1-r)	3
5.	Y responds to A_1	q x r^3 x (1-r)	5*
6.	Y responds to A_2	q x r^4 x (1-r)	6
7.	Y responds to A_3	q x r^5 x (1-r)	7
8.	X send message to supervisor	q x r^6	8

Figure H.1 shows a diagram of the events described above.

The expected number of overhead blocks transmitted is

$$EOH = \sum_{i=1}^{8} P(Ei) \times N(Ei),$$

where Ei = event i,

P(Ei) = the probability that event i will occur,

N(Ei) = the number of blocks transmitted as a result of event i,

EOH = expected overhead.

$$EOH = q(1-r)\,(1 + 2r + 3r^2 + 5r^3 + 6r^4 + 7r^5) + 8qr^6$$

If r and q are assumed to be the same with a value of 0.005, then

$$EOH = 0.005.$$

This is the expected number of retransmitted frames per one frame transmitted or a 0.5% overhead.

---

* Afer sending three R-R sequences the establishment procedure is instituted. This is assumed to be one block. Note that EOT is only one character.

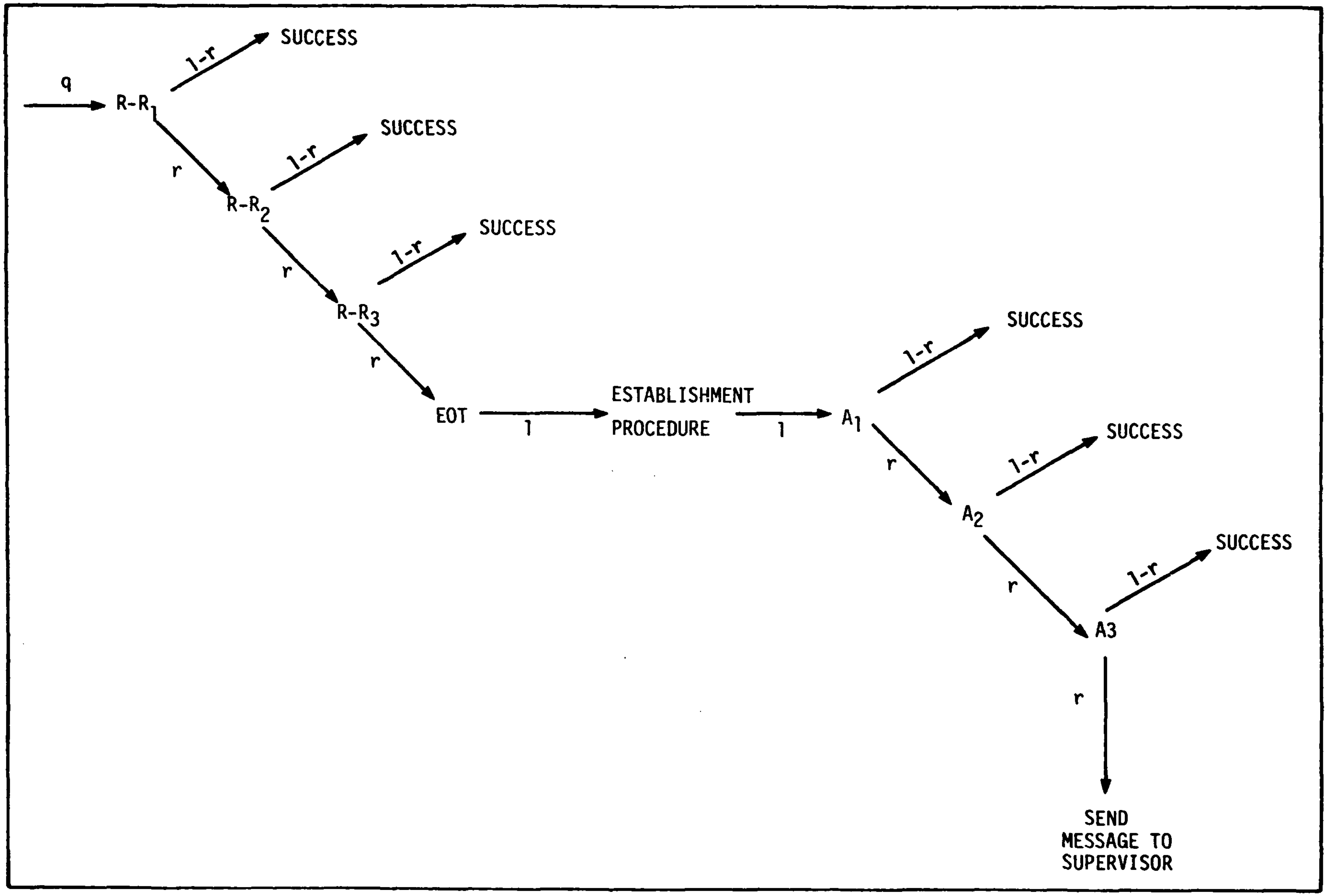

FIGURE H.1: MESSAGE RECOVERY PROCEDURES

APPENDIX I

ARRIVAL RATES FOR NFDC/IS CIRCUITS

I.1 Purpose

The total bit rate (TBR) of arrival for NFDC/IS circuits is determined. Two basic circuit categories are examined: NFDC-CNS/AIS and switch-switch/switch-external system. The NFDC-CNS/AIS category is examined for all four NADIN support alternatives; the switch-switch/switch-external systems category is the same for all alternatives. The protocol and message overheads determined in Appendix F are applied to the traffic in each category to determined the TBR.

I.2 Formulas and Calculations

The TBR is determined by summing the bit rates (BR) of all traffic on a given circuit and multiplying the aggregate bit rate (ABR) by the protocol overhead (1 + POH) factor. The model is given below and the results are summarized in Table I.1.

$$TBR = ABR \bullet (1 + POH),$$

where $$ABR = \sum_{i=1}^{nj} BRij,$$

BRij = bit rate for message type i of circuit j in bits per second (b/s) and

nj = The number of message types for circuit j.

NFDC-CNS/AIS: ALTERNATIVE 1

CIRCUIT	MESSAGE TYPE	(1) BIT RATE (BR)	(1) AGGREGATE BIT RATE (ABR)	PROTOCOL OVERHEAD (POH)	(1) TOTAL BIT RATE (TBR)
NFDC → ZDC	NOTAMS	24	24	1.482	36
ZDC → NFDC	NOTAMS	64	64	1.438	92
ZDC → ZTL	NOTAMS CONC → SW	24 208	232	1.204	208
ZTL → ZDC	NOTAMS SW → CONC	64 288	352	1.223	431
ZTL → CNS	NOTAMS	88	88	1.438	127
CNS → ZTL	NOTAMS	48	48	1.482	72
NFDC → AIS	INTERACTIVE AIS	112	(2) 184	1.586	292
AIS → NFDC	INTERACTIVE AIS	72	(2) 184	1.586	292
NFDC → AIS	BATCH AIS	72	(2) 10,072	1.165	11,734
AIS → NFDC	BATCH AIS	10,000	(2) 10,072	1.165	11,734

TABLE I.1: TOTAL BIT RATES FOR NFDC/IS CIRCUITS

NFDC-CNS/AIS: ALTERNATIVE 2

CIRCUIT	MESSAGE TYPE	(1) BIT RATE (BR)	(1) AGGREGATE BIT RATE (ABR)	PROTOCOL OVERHEAD (POH)	(1) TOTAL BIT RATE (TBR)
NFDC ⟶ ZDC	NOTAMs INTERACTIVE AIS	24 112	136	1.482	202
ZDC ⟶ NFDC	NOTAMs INTERACTIVE AIS	64 72	136	1.438	196
ZDC ⟶ ZTL	NOTAMs INTERACTIVE AIS CONC ⟶ SW	24 112 208	344	1.204	415
ZTL ⟶ ZDC	NOTAMs INTERACTIVE AIS SW ⟶ CONC	64 72 288	424	1.223	519
ZTL ⟶ CNS/AIS	NOTAMs INTERACTIVE AIS	88 112	200	1.438	288
CNS/AIS ⟶ ZTL	NOTAMs INTERACTIVE AIS	88 72	160	1.482	238
NFDC ⟶ AIS	BATCH AIS	72	(2) 10,072	1.165	11,734
AIS ⟶ NFDC	BATCH AIS	10,000	(2) 10,072	1.165	11,734

TABLE I.1: TOTAL BIT RATES FOR NFDC/IS CIRCUITS (Continued)

NFDC-CNS/AIS: ALTERNATIVE 3

CIRCUIT	MESSAGE TYPE	(1) BIT RATE (BR)	(1) AGGREGATE BIT RATE (ABR)	PROTOCOL OVERHEAD (POH)	(1) TOTAL BIT RATE (TBR)
NFDC → CNS	NOTAMs	24	24	1.482	36
CNS → NFDC	NOTAMs	64	64	1.438	92
NFDC → AIS	INTERACTIVE AIS	112	(2) 184	1.586	292
AIS → NFDC	INTERACTIVE AIS	72	(2) 184	1.586	292
NFDC → AIS	BATCH AIS	72	(2) 10,072	1.165	11,734
AIS → NFDC	BATCH AIS	10,000	(2) 10,072	1.165	11,734
CNS → ZTL	NOTAMs	48	(2) 112	1.471	165
ZTL → CNS	NOTAMs	64	(2) 112	1.427	160

TABLE I.1: TOTAL BIT RATES FOR NFDC/IS CIRCUITS (Continued)

NFDC-CNS/AIS: ALTERNATIVE 4

CIRCUIT	MESSAGE TYPE	(1) BIT RATE (BR)	(1) AGGREGATE BIT RATE (ABR)	PROTOCOL OVERHEAD (POH)	(1) TOTAL BIT RATE (TBR)
NFDC → ZDC	NOTAMS INTERACTIVE AIS BATCH AIS	24 112 72	208	1.482	309
ZDC → NFDC	NOTAMS INTERACTIVE AIS BATCH AIS	64 72 10,000	10,136	1.438	14,576
ZDC → ZTL	NOTAMs INTERACTIVE AIS BATCH AIS CONC → SW	24 112 72 208	416	1.204	501
ZTL → ZDC	NOTAMs INTERACTIVE AIS BATCH AIS SW → CONC	64 72 10,000 288	10,424	1.223	12,750
ZTL → CNS/AIS	NOTAMs INTERACTIVE AIS BATCH AIS	88 112 72	272	1.438	392
CNS/AIS → ZTL	NOTAMs INTERACTIVE AIS BATCH AIS	88 72 10,000	10,160	1.482	15,058

TABLE I.1: TOTAL BIT RATES FOR NFDC/IS CIRCUITS (Continued)

SWITCH-TO-SWITCH AND SWITCH-TO-EXTERNAL

CIRCUIT	MESSAGE TYPE	(1) BIT RATE (BR)	(1) AGGREGATE BIT RATE (ABR)	PROTOCOL OVERHEAD (POH)	(1) TOTAL BIT RATE (TBR)
ZTL → ZLC	NOTAMs SWITCH-SWITCH	20 720	740	1.204	891
ZLC → ZTL	NOTAMs SWITCH-SWITCH	8 720	728	1.204	877
SWITCH → AWP	NOTAMs SW → AWP	48 3,016	3,064	1.571	4,814
AWP → SWITCH	NOTAMs AWP → SW	8 2,176	2,184	1.452	3,172
SWITCH → WMSC	NOTAMs SW → WMSC	20 296	316	1.427	452
WMSC → SWITCH	NOTAMs WMSC → SW	12 616	628	1.953	1,227

NOTES:

1. Bit rates are given in bits per second (b/s).
2. The ABR is defined as the sum of the BRs in both directions for half-duplex protocols.

TABLE 1.1: TOTAL BIT RATES FOR NFDC/IS CIRCUITS (Concluded)

APPENDIX J

NFDC/IS CIRCUIT UTILIZATION

J.1 Purpose

The circuit utilization (U) is given for two categories of NFDC/IS circuits: NFDC-CNS/AIS and switch-switch/switch-external systems. The NFDC-CNS/AIS category is examined for the four NADIN support alternatives; the switch-switch/switch-external systems category is the same for all alternatives. The line speed (LS) for the circuits was determined such that U was less than unity and the delays (see Appendix K) were considered acceptable.

J.2 Formulas and Calculations

Circuit utilization, U, is defined by the ratio of the total bit rate, TBR, (which was determined in Appendix E) and the line speed, LS. That is,

$$U = TBR/LS,$$

where both TBR and LS are expressed in bits per second (b/s).

The results are summarized in Table J.1.

NFDC-CNS/AIS: ALTERNATIVE 1

CIRCUIT	TOTAL BIT RATE (TBR)	LINE SPEED (LS)	UTILIZATION (U)
NFDC ⟶ ZDC	36	1,200	0.030
ZDC ⟶ NFDC	92	1,200	0.077
ZDC ⟶ ZTL	280	4,800	0.058
ZTL ⟶ ZDC	431	4,800	0.090
ZTL ⟶ CNS	127	1,200	0.106
CNS ⟶ ZTL	72	1,200	0.060
NFDC ⟶ AIS (INTERACTIVE)	292	1,200	0.243
AIS ⟶ NFDC (INTERACTIVE)	292	1,200	0.243
NFDC ⟶ AIS (BATCH)	11,734	19,200	0.611
AIS ⟶ NFDC (BATCH)	11,734	19,200	0.611

TABLE J.1: NFDC/IS CIRCUIT UTILIZATION

NFDC-CNS/AIS: ALTERNATIVE 2

CIRCUIT	TOTAL BIT RATE (TBR)	LINE SPEED (LS)	UTILIZATION (U)
NFDC → ZDC	202	2,400	0.084
ZDC → NFDC	196	2,400	0.082
ZDC → ZTL	415	4,800	0.086
ZTL → ZDC	519	4,800	0.108
ZTL → CNS/AIS	288	2,400	0.120
CNS/AIS → ZTL	238	2,400	0.099
NFDC → AIS	11,734	19,200	0.611
AIS → NFDC	11,734	19,200	0.611

TABLE J.1: NFDC/IS CIRCUIT UTILIZATION (Continued)

NFDC-CNS/AIS: ALTERNATIVE 3

CIRCUIT	TOTAL BIT RATE (TBR)	LINE SPEED (LS)	UTILIZATION (U)
NFDC ⟶ CNS	36	1,200	0.030
CNS ⟶ NFDC	92	1,200	0.077
NFDC ⟶ AIS	292	1,200	0.243
AIS ⟶ NFDC	292	1,200	0.243
NFDC ⟶ AIS	11,734	19,200	0.611
AIS ⟶ NFDC	11,734	19,200	0.611
CNS ⟶ ZTL	165	1,200	0.138
ZTL ⟶ CNS	160	1,200	0.133

TABLE J.1: NFDC/IS CIRCUIT UTILIZATION (Continued)

NFDC-CNS/AIS: ALTERNATIVE 4

CIRCUIT	TOTAL BIT RATE (TBR)	LINE SPEED (LS)	UTILIZATION (U)
NFDC ⟶ ZDC	309	19,200	0.016
ZDC ⟶ NFDC	14,576	19,200	0.759
ZDC ⟶ ZTL	501	19,200	0.026
ZTL ⟶ ZDC	12,750	19,200	0.664
ZTL ⟶ CNS/AIS	392	19,200	0.020
CNS/AIS ⟶ ZTL	15,058	19,200	0.784

TABLE J.1: NFDC/IS CIRCUIT UTILIZATION (Continued)

SWITCH TO SWITCH AND SWITCH TO EXTERNAL SYSTEMS

CIRCUIT	TOTAL BIT RATE (TBR)	LINE SPEED (LS)	UTILIZATION (U)
ZTL → ZLC	891	19,200	0.046
ZLC → ZTL	877	19,200	0.046
SWITCH → AWP	4,814	9,600	0.501
AWP → SWITCH	3,172	9,600	0.330
SWITCH → WMSC	452	4,800	0.094
WMSC → SWITCH	628	4,800	0.131

TABLE J.1: NFDC/IS CIRCUIT UTILIZATION (Concluded)

APPENDIX K

NFDC/IS DELAY CATEGORIES

K.1 PURPOSE

Delays for four categories are determined for the NADIN support alternatives: NOTAMS (one-way delay between NFDC and CNS), interactive AIS (end-to-end delay between NFDC and AIS), backbone (one-way delay between NADIN concentrators homed to opposite switches) and external systems (one-way delay between the CNS and the AWPs or the WMSC). For the first two categories, the delays are determined for each of the four alternatives; for the backbone category delays are determined for two line sizes for the Washington to Atlanta backbone link and for the external systems category delays are calculated based on three lines sizes between the CNS and the Atlanta NADIN switch.

K.2 FORMULAS AND CALCULATIONS

The expected total delay for a particular message type is given by the sum of the waiting times and the transmission times incurred on the circuits. The general model for average delay, D, for a particular message type on a link is given by:

$$D = \sum_{i=1}^{n} Tqi = \sum_{i=1}^{n} (Tw_i + Ts_i),$$

where Tq_i = queueing time for the message type on circuit i of the link,

Tw_i = waiting time for all message types on circuit i of the link,

Ts_i = service time for the message type on circuit i of the link and

n = the number of circuits on the link.

The circuits in alternatives 1, 2 and 3 are modeled as M/M/1 queueing systems with first-in, first-out (FIFO) service discipline. The total queueing time, Tq, for a particular message type consists of transmission time plus delay and is given by:

$$Tq = \frac{T_{\bar{s}} \bullet U}{1-U} + Ts,$$

where $T_{\bar{s}}$ = mean service time for all message types,

Ts = mean service time for the particular message type and

U = line utilization.

In alternative 4, which considers batch and interactive traffic on the same line, the queueing model used is again the M/M/1 system; however, the service discipline is considered to be a nonpreemptive priority scheme with interactive messages (NOTAMs and interactive AIS messages) having priority over batch AIS messages. It is assumed that batch messages are segmented with the maximum segment size of 3,700 characters. Thus, the delay for interactive messages is given by

$$Tq = \frac{U \bullet T_{\bar{s}}}{1-U_1} + T_{s_1} ,$$

where U = average line utilization,

u_1 = line utilization due to interactiver traffic,

$T_{\bar{s}}$ = average service time and

T_{s_1} = average service time for NOTAM or interactive AIS messages.

The details of the delay calculations are given in Table K.1. A summary for the four categories is given below.

Alternative 1:

(i)	NFDC-CNS (one-way)	3.197 seconds*
(ii)	NFDC-AIS (end-to-end)	1.144 seconds
(iii)	Backbone (one-way)	0.513 seconds*
(iv)	External Systems (one-way, average)	1.253 seconds*

Alternative 2:

(i)	NFDC-CNS (one-way)	1.752 seconds*
(ii)	NFDC-AIS (end-to-end)	1.266 seconds
(iii)	Backbone (one-way)0.513 seconds*	
(iv)	External Systems (one-way, average)	0.788 seconds

Alternative 3:

(i)	NFDC-CNS (one-way)	1.430 seconds*
(ii)	NFDC-AIS (end-to-end)	1.144 seconds
(iii)	Backbone (one-way)0.513 seconds*	
(iv)	External Systems (one-way, average)	1.253 seconds

Alternative 4:

(i)	NFDC-CNS	0.788 seconds*
(ii)	NFDC-AIS (end-to-end)	0.704 seconds
(iii)	Backbone (one-way)0.443 seconds	
(iv)	External Systems (one-way, average)	0.552 seconds

* For one-way delay where the time for one direction is not the same as the time for opposite direction for a circuit, the maximum of the two times is given.

NFDC-CNS/AIS: ALTERNATIVE 1

CIRCUIT	(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
NFDC ⟶ ZDC	984	1,200	0.030	0.820	0.025	0.0845
ZDC ⟶ NFDC	1,584	1,200	0.077	1.320	0.110	1.430
ZDC ⟶ ZTL	984	4,800	0.058	0.205	0.013	0.218
ZTL ⟶ ZDC	1,584	4,800	0.090	0.330	0.033	0.363
ZTL ⟶ CNS	984	1,200	0.106	0.820	0.097	0.917
CNS ⟶ ZTL	1,584	1,200	0.060	1.320	0.084	1.404
NFDC ⟶ AIS	640	1,200	0.243	0.533	0.171	0.704
AIS ⟶ NFDC	400	1,200	0.243	0.333	0.107	0.440

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS

NFDC-CNS/AIS: ALTERNATIVE 2

CIRCUIT	(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
NFDC ZDC	984 / 640	2,400	0.084	0.410 / 0.267	0.028	0.438 / 0.295
ZDC NFDC	1,584 / 400	2,400	0.082	0.660 / 0.167	0.035	0.695 / 0.202
ZDC ZTL	984 / 640	4,800	0.086	0.205 / 0.134	0.013	0.218 / 0.147
ZTL ZDC	1,584 / 400	4,800	0.108	0.330 / 0.084	0.024	0.354 / 0.108
ZTL CNS	984 / 640	2,400	0.120	0.410 / 0.267	0.037	0.447 / 0.304
CNS ZTL	1,584 / 400	2,400	0.099	0.660 / 0.167	0.043	0.703 / 0.210

Total queueing time, T_q, and service time, T_s, are determined for two classes of average message lengths, AML. The top number for the AML, T_s, and T_q, columns represent NOTAMs and the bottom number represents interactive AIS messages.

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Continued)

NFDC-CNS/AIS: ALTERNATIVE 3

CIRCUIT	(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
NFDC ⟶ CNS	984	1,200	0.030	0.820	0.025	0.845
CNS ⟶ NFDC	1,584	1,200	0.077	1.320	0.110	1.430
NFDC ⟶ AIS	640	1,200	0.243	0.533	0.171	0.704
AIS ⟶ NFDC	400	1,200	0.243	0.33	0.107	0.440

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Continued)

NFDC-CNS/AIS: ALTERNATIVE 4

CIRCUIT	(1) AML_1	(2) LS	U	U_1	(3) T_{s_1}	(3) T_s	(3) T_w	(3) T_q
NFDC→ZDC	984 / 640	19,200	0.016	0.021	0.051 / 0.033	0.054	0.001	0.052 / 0.034
ZDC→NFDC	1,584 / 400	19,200	0.759	0.020	0.083 / 0.021	0.162	0.037	0.120 / 0.058
ZDC→ZTL	984 / 640	19,200	0.026	-----	0.051 / 0.033	0.054	0.001	0.052 / 0.034
ZTL→ZDC	1,584 / 400	19,200	0.664	-----	0.083 / 0.021	0.188	0.372	0.455 / 0.393
ZTL→CNS	984 / 640	19,200	0.020	0.021	0.054 / 0.033	0.054	0.001	0.055 / 0.034
CNS→ZTL	1,584 / 400	19,200	0.784	0.020	0.083 / 0.021	0.162	0.130	0.213 / 0.151

Total quequeing time, T_q, and service time, T_{s_1}, are determined for two classes of average message lengths, AML. The top number of the AML, T_{s_1}, and T_q columns represents NOTAMs and the bottom number represents Interactive AIS Messages.

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Continued)

BACKBONE

CIRCUIT	(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
NC ⟶ ZLC	1,000	4,800	0.052	0.208	0.011	0.219
ZLC ⟶ NC	1,000	4,800	0.074	0.208	0.017	0.225
ZLC ⟶ ZTL	1,000	19,200	0.046	0.052	0.003	0.055
ZTL ⟶ ZLC	1,000	19,200	0.046	0.052	0.003	0.055
ZTL ⟶ (5) ZDC	1,000	4,800	0.086	0.208	0.020	0.228
ZDC ⟶ (5) ZTL	1,000	4,800	0.108	0.208	0.025	0.233
ZTL ⟶ (5) ZDC	1,000	19,200	0.026	0.052	0.001	0.053
ZDC ⟶ (5) ZTL	1,000	19,200	0.664	0.052	0.103	0.155

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Continued)

EXTERNAL SYSTEMS

CIRCUIT	(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
CNS → ZTL	1,000	1,200	0.167	0.833	0.167	1.000
ZTL → CNS	1,000	1,200	0.162	0.833	0.161	0.994
CNS → ZTL	1,000	2,400	0.221	0.417	0.118	0.535
ZTL → CNS	1,000	2,400	0.214	0.417	0.114	0.531
CNS → ZTL	1,000	19,200	0.799	0.052	0.207	0.259
ZTL → CNS	1,000	19,200	0.775	0.052	0.179	0.231
ZTL → AWP_1	1,000	9,600	0.501	0.104	0.104	0.208
AWP_1 → ZTL	1,000	9,600	0.330	0.104	0.051	0.155

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Continued)

EXTERNAL SYSTEMS (Continued)

CIRCUIT		(1) AML	(2) LS	U	(3) T_s	(3) T_w	(3) T_q
ZTL	ZLC	1,000	19,200	0.046	0.052	0.003	0.055
ZLC	ZTL	1,000	19,200	0.046	0.052	0.003	0.055
ZLC	AWP_2	1,000	9,600	0.501	0.104	0.104	0.208
AWP_2	ZLC	1,000	9,600	0.330	0.104	0.051	0.155
ZTL	WMSC	1,000	4,800	0.094	0.208	0.022	0.230
WMSC	ZTL	1,000	4,800	0.131	0.208	0.131	0.239

NOTES:

1. Average Message Length is given in bits.
2. Line Speed is given in b/s.
3. Service Time, waiting, and Queueing Time are given in seconds.
4. The Line Speed for the CNS-ZTL link is 1,200 b/s for Alternatives 1 and 3; 2,400 bits for Alternative 2; and 19,200 b/s for Alternative 4.
5. The Line Speed for the ZTL-ZDC link is 4,800 b/s for alternatives 1, 2, and 3; 19,200 for Alternative 4.

TABLE K.1: DELAYS FOR NFDC/IS CIRCUITS (Concluded)

APPENDIX L

COST ASSUMPTIONS AND CALCULATIONS

L.1 PURPOSE

Assumptions made concerning the cost of network components and the calculations for the cost of each NADIN support alternative are given in this appendix. The cost assumptions relate to hardware components, transmission facilities and cost relationships. The costs are grouped into one-time and recurring costs.

L.2 HARDWARE COMPONENTS

The hardware components required in the four NADIN support alternatives are modems and biplexors. The prices for modems are for 1200, 2400 and 9600 bit per second (b/s) models. The biplexors are used to construct 19,200 b/s lines from two 9,600 b/s lines. The monthly maintenance cost of the equipment is estimated to be 1.5 percent of the purchase price. Purchase and maintenance costs are summarized below.

Hardware Component	Purchase Price ($)	Maintenance Cost Per Month ($)
1200 b/s Modem	500	4.50
2400 b/s Modem	2,000	30.00
9600 b/s Modem	9,000	135.00
Biplexor	5,000	75.00

L.3 TRANSMISSION FACILITIES

There are two categories of transmission facilities considered for serving the NFDC/IS data communications requirements: voice-grade lines and local cable connections. For communications links where NADIN will not be used, voice-grade lines are considered. For connections within the Atlanta NADIN switching center building cable connection will be used. Cost information for the two categories are summarized below.

Voice-Grade Lines

Voice-grade lines are provided to governmental agencies at Telpak rates. These lines have a maximum 9600 b/s capacity, and two lines may be used to construct one 19,200 b/s line.

Installation Cost/Drop	Cost/Month
\$50	\$43.30/1st drop + 21.65/additional drop + 0.54/mile

Cable Connection

It is assumed that a pair of cables of a maximum length of a few hundred feet will be sufficient to provide a high speed connection between systems collocated at the NADIN switching center in Atlanta. The purchase and installation costs are estimated to be \$1000.

L.4 COST RELATIONSHIPS

In order to accurately reflect total life cycle costs, (one-time and recurring expenses) present value techniques have been employed. The objective is to integrate one-time and recurring costs, over time, to generate a present value figure for each alternative under study.

Present value, Y_0, of a given cost, Y_1, to be incurred at t_1 is essentially the amount of money that must be put in the bank today, t_0, such that with interest accumulating at rate r there will be Y_1 dollars in the bank at t_1. Y_0 can be determined as follows:

$$Y_0 = Y_1 (1 + r)^{-n}$$

where:

$$r = \text{annual compounded rate}$$

$$n = t_1 - t_0$$

This general technique can be extended to develop the present value for recurring and one-time costs incurred to realize a given network design. One-time expenses over the life cycle period will be calculated for two static points in time: 1983 and 1988. Recurring expenses are shown as linearly increasing functions over the intervals 1983-1988 and 1988-2000.

The present value life cycle costs for each of the four NADIN support alternatives are calculated according to the equations given below:

$$LC = 0.788\ OTC_{83} + 0.489\ OTC_{88} + N_{83/88}\ (0.489)\ RC_{83/88} + N_{88/2000}\ (0.189)\ RC_{88},$$

where

LC = life cycle cost,

OTC = one-time cost incurred at the beginning of year i,

$RC_{i/j}$ = average monthly recurring costs between year i and year j and

$N_{i/j}$ = number of months between year i and year j.

L.5 CALCULATIONS

The one-time and recurring costs that will be incurred for each of the four NADIN support alternatives are determined for the three time points 1983, 1988 and 2000. The figures represent unadjusted costs (i.e., present value figures have not been applied).

Alternative 1

1983: One-Time Costs

Hardware Equipment Purchases

Modems: 2 @ $500/unit	$ 1,000.00

Installations

Voice Grade Circuits: 1 @ $50/drop	$ 100.00
Cable Connections: 1 @ $100/conn.	$ 1,000.00

Total = $2,100

Recurring Costs

Hardware Maintenance

Modems: 2 @ $4.50/unit	$ 9.00

Communications Facilities

Voice Grade Circuits: 1 for 35 miles	$ 83.85

Total = $92.85/month

1988: <u>One-Time Costs</u>

Hardware Equipment Purchases

Modems: 2 @ $500/unit	$ 1,000.00
Modems: 4 @ $900/unit	$ 3,600.00
Biplexors: 2 @ $5,000/unit	$10,000.00

Installations

Voice Grade Circuits: 3 @ $50/drop	$ 300.00

Total = $47,300

<u>Recurring Costs</u>

Hardware Maintenance

Modems: 4 @ $4.50/unit	$ 18.00
Modems: 4 @ $135/unit	$ 540.00
Biplexors: 2 @ $75/unit	$ 150.00

Communications Facilities

Voice Grade Circuits: 3 for 550 miles:	$ 1,085.85
Voice Grade Circuits: 1 for 35 miles:	$ 83.85

Total = $1,877.70

2000: <u>One-Time Costs</u>

None

Recurring Costs

Same as 1988: Total = $1,877.70

Alternative 2

1983: One-Time Costs

Hardware Equipment Purchases

Modems: 2 @ $2,000/unit	$ 4,000.00

Installations

Voice Grade Circuits: 1 @ $50/drop	$ 100.00
Cable Connections: 1 @ $1,000/conn.	$ 1,000.00

Total = $5,100

Recurring Costs

Modems: 2 @ $30/unit	$ 60.00

Communications Facilities

Voice Grade Circuits: 1 for 35 miles	$ 83.85

Total = $143.85

1988: One-Time Costs

Hardware Equipment Purchases

Modems: 4 @ $9,000/unit	$36,000.00

Biplexors: 2 @ $5,000/unit	$10,000.00

Installations

Voice Grade Circuits: 2 @ $50/drop	$ 200.00

Total = $46,200

Recurring Costs

Hardware Maintenance

Modems: 4 @ $135/unit	$ 540.00
Modems: 2 @ $30/unit	$ 60.00
Biplexors: 2 @ $75/unit	$ 150.00

Communications Facilities

Voice Grade Circuits: 2 for 550 miles	$ 723.90
Voice Grade Circuits: 1 for 35 miles	$ 83.85

Total = $1,557.75

2000: One-Time Costs

None

Recurring Costs

Same as 1988: Total = $1,557.75

Alternative 3

1983: One-Time Costs

Hardware Equipment Purchases

Modems: 2 @ $500/unit	$ 1,000.00

Installations

Voice Grade Circuits: 1 @ $50/drop	$ 100.00
Cable Connections: 1 @ $1,000/conn.	$ 1,000.00

Total = $2,100

Recurring Costs

Hardware Maintenance

Modems: 2 @ $4.50/unit	$ 9.00

Communications Facilities

Voice Grade Circuits: 1 for 550 miles	$ 361.95

Total = $370.95

1988: One-Time Costs

Hardware Equipment Purchases

Modems: 2 @ $500/unit	$ 1,000.00
Modems: 4 @ $9,000/unit	$36,000.00
Biplexors: 2 @ $5,000/unit	$10,000.00

Installations

Voice Grade Circuits: 3 @ $50/drop $ 300.00

Total = $47,300

Recurring Costs

Hardware Maintenance

Modems: 4 @ $4.50/unit	$ 18.00
Modems: 4 @ $135/unit	$ 540.00
Biplexors: 2 @ $75/unit	$ 150.00

Communications Facilities

Voice Grade Circuits: 4 for 550 miles $ 1,447.80

Total = $2,155.80

2000 One-Time Costs

None

Recurring Costs

Same as 1988: Total = $2,155.80

Alternative 4

1983: One-Time Costs

Hardware Purchases

Modems: 2 @ $500/unit $ 1,000.00

Installations

Voice Grade Circuits: 1 @ $50/drop	$ 100.00
Cable Connection: 1 @ $1,000/conn.	$ 1,000.00

Total = $2,100

Recurring Costs

Hardware Maintenance

Modems: 2 @ $4.50/unit	$ 9.00

Communications Facilities

Voice Grade Circuits: 1 for 35 miles	$ 83.85

Total = $92.85

1988: One-Time Costs

Hardware Equipment Purchases

Modems: 8 @ $9,000/unit	$72,000.00
Biplexors: 2 @ $5,000/unit	$10,000.00

Installations

Voice Grade Circuits: 2 @ $50/drop	$ 200.00

Total = $92,200

Recurring Costs

Hardware Maintenance

Modems: 8 @ $135/unit	$ 1,080.00
Biplexors: 2 @ $75/unit	$ 150.00

Communications Facilities

Voice Grade Circuits: 1 for 550 miles	$ 345.75
Voice Grade Circuits: 2 for 35 miles	$ 167.70

Total = $1,893.45

2000: One-Time Costs

None

Recurring Costs

Same as 1988: Total = $1,893.45

The unadjusted one-time and recurring costs are summarized for the three time points and four NADIN support alternatives in Table L.1.

ALTERNATIVE 1			
COST CATEGORY	TIME POINTS		
	1983	1988	2000
ONE-TIME COST	$ 2,100.00	$47,300.00	0
RECURRING COST	$ 92.85	$ 1,877.70	$1,877.70

ALTERNATIVE 2			
COST CATEGORY	TIME POINTS		
	1983	1988	2000
ONE-TIME COST	$ 5,100.00	$46,200.00	0
RECURRING COST	$ 143.85	$ 1,557.75	$1,557.75

TABLE L.1: UNADJUSTED ONE-TIME AND RECURRING COSTS

ALTERNATIVE 3			
COST CATEGORY	TIME POINTS		
	1983	1988	2000
ONE-TIME COST	$ 2,100.00	$47,300.00	0
RECURRING COST	$ 370.95	$ 2,155.80	$2,155.80

ALTERNATIVE 4			
COST CATEGORY	TIME POINTS		
	1983	1988	2000
ONE-TIME COST	$ 2,100.00	$ 92,200	0
RECURRING COST	$ 92.85	$ 1,893.45	$1,893.45

TABLE L.1: UNADJUSTED ONE-TIME AND RECURRING COSTS (Concluded)

DATE
ILME